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DEVELOPMENT OF A STANDARD CONNECTOR FOR ORBITAL REPLACEMENT UNITS FOR SERVICEABLE SPACECRAFT

Ellen F. Heath, Matthew A. Braccio,
Steven D. Raymus, and David W. Gross*

ABSTRACT

The current trend for spacecraft to be serviceable and repairable in orbit has led to a modular approach to satellite subsystem design. Spacecraft equipment, such as, sensors, tape recorders, computers, transponders, batteries, etc., housed in discrete modular units--called Orbital Replacement Units (ORUs)--can be attached and detached to the spacecraft as needed. The interface between the ORU and the spacecraft is crucial. The projected use of robotics and the need for a common mechanism capable of performing several functions puts many constraints on the design of the interface. Astro-Space Division has designed and developed such an interface mechanism--called the Standard Interface Connector (SIC)--that mates the ORU to the spacecraft. The SIC also provides for the flow of fluids, data, and power between the module and spacecraft. The baseline design presented in this paper can be configured to provide various attachment schemes. Tests on SIC models have demonstrated the functionality of the design and its compatibility with current robotics.

INTRODUCTION

Early servicing of spacecraft will almost certainly be done by extra vehicular activity (EVA) crewmembers, using tools such as NASA's Module Servicing Tool (MST). Later, the Space Station Orbital Maneuvering Vehicle (OMV) repair vehicle will permit in-orbit servicing, using the same connector mechanism with a robot arm under supervisory control. Making the ORU exchange process autonomous provides a more cost-effective, repeatable operation than one requiring astronaut intervention. This, however, places more restrictions on the design of the interface between the modules and spacecraft. It must be compatible with existing and proposed robotic systems; provide a stable mount for delicate instruments; and provide for power, data, and fluid transmission across the interface.

SIC DESIGN

Several candidate SIC designs were established as the result of trade-offs of more than ten connector concepts. The factors that drove the design are as follows:

- The SIC must be robot friendly, yet suitable for extra vehicular activity (EVA) astronauts.

*Astro-Space Division, RCA Aerospace and Defense, East Windsor, N.J.

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- The SIC design must be applicable to payloads, ORUs, and perhaps in the case of the Space Station, payloads attached to its structural framework.

- The SIC must perform several functions: assist in aligning the ORU to the platform, mate utility connectors, and provide proper mechanical attachment to ensure pointing accuracy.

- Alignment, attachment, and connector mating must be accomplished simultaneously with one actuation.

- The platform must be able to accommodate ORUs and payloads of different sizes and shapes. A platform with no protrusions would allow for a flexible layout of replaceable units. Therefore, the SIC mating ports had to be designed so that the ORUs could be flush with the platform surface.

- The mechanism housing must be usable as a transport handle.

The candidate SIC designs are variations of a baseline, the only differences being each tie-down configuration. The general arrangement is shown in Figure 1. The baseline design, based on proven technology of NASA's Multimission Modular Spacecraft (MMS) project, relies on the concept of a load-spreader beam transmitting loads to restraint pins at its corners. The load-spreader beam houses the mechanism through which all connections are initiated and achieved. A handle extending from the upper surface of the load-spreader beam is compatible with a modified MST and thus can be used by an astronaut or robot. A centrally located preload bolt--also of MMS heritage--is mated with a funnel-shaped socket on the platform and provides initial

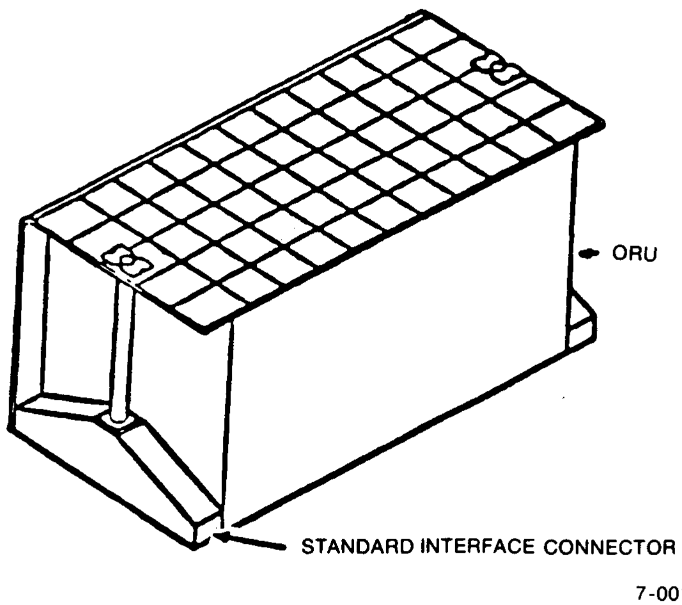

Figure 1. General Arrangement: ORU/SIC Configuration

alignment and attachment. Once the screw makes contact with its mating socket on the platform, turning it drives a carrier containing all connectors into position. Preload, obtained by tightening the screw, is transmitted through the load-spreader beam to the two nearest corners of the ORU. The preload provides mounting restraint points for the ORU. Greater detail on the locations of attachment devices and connectors on the load-spreader beam and the spacecraft platform are shown in Figure 2. This baseline connector design satisfies requirements for simplicity and efficiency, because all functions providing alignment, attachment, and utility connection are housed in one load-spreader beam.

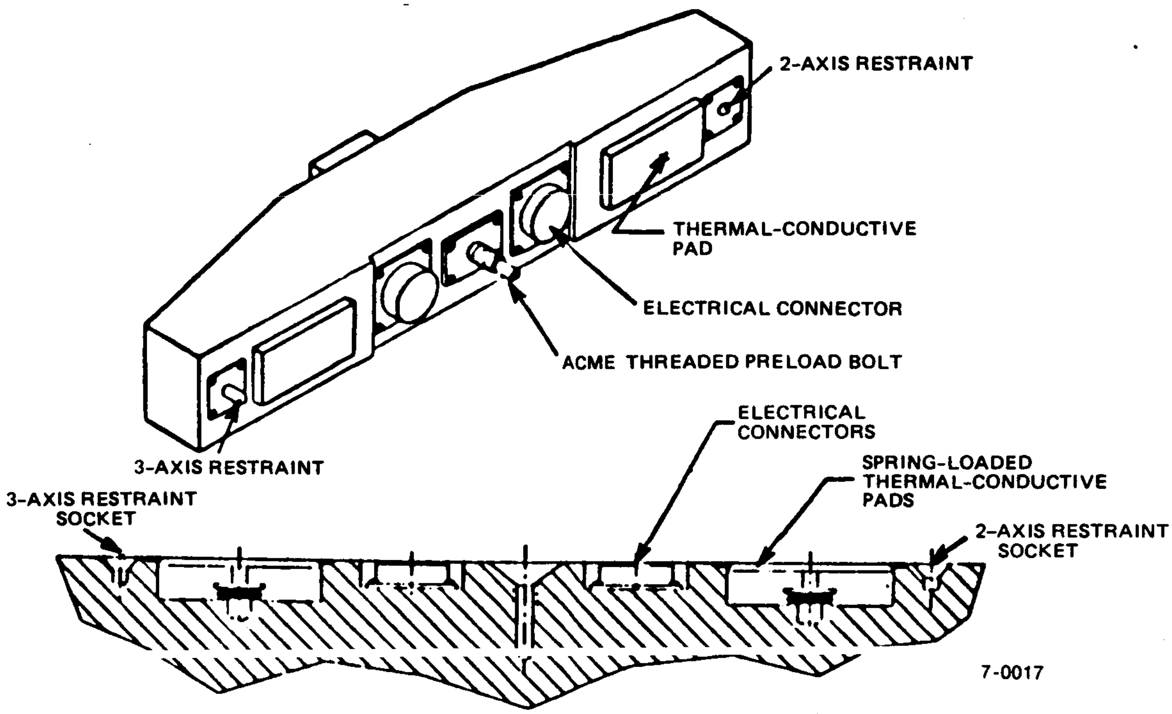

Figure 2. SIC-to-Platform Interface

The candidate designs were derived from all possible attachment configurations of the baseline design. The preferred configuration for the Space Station platforms is an ORU having an SIC at each end, giving it a four-point mount. If the two-axis and three-axis restraint pins are eliminated from one SIC, a three-point mount results. Another variation of a three-point mount is obtained with only one SIC when a push rod assembly is added. The advantages of the three-point mount are many:

- the mounting is statically determinant
- it provides the minimum number of points required to constrain the six degrees of freedom of the structures
- it prevents differential bending or thermal expansion from inducing loads in the structures

- it makes single action attachment possible because the turning of one bolt activates all three restraint pins

A cut-away drawing of these variations is shown in Figure 3. A three-point mount can be achieved without the push-rod assembly using a spring-loaded pin and ball that has been forced into a socket, as shown in Figure 4. The major disadvantage of this design is that it requires a robotic servicer to perform a cocking movement. A final three-point mount configuration being considered locates the SIC at right angles to the baseplate, as shown in Figure 5. The turning bolt directly draws the ORU into position at the edge of the spacecraft platform. However, flexibility of platform layout is limited by this design, because all ORUs or payloads require a platform edge to attach to.

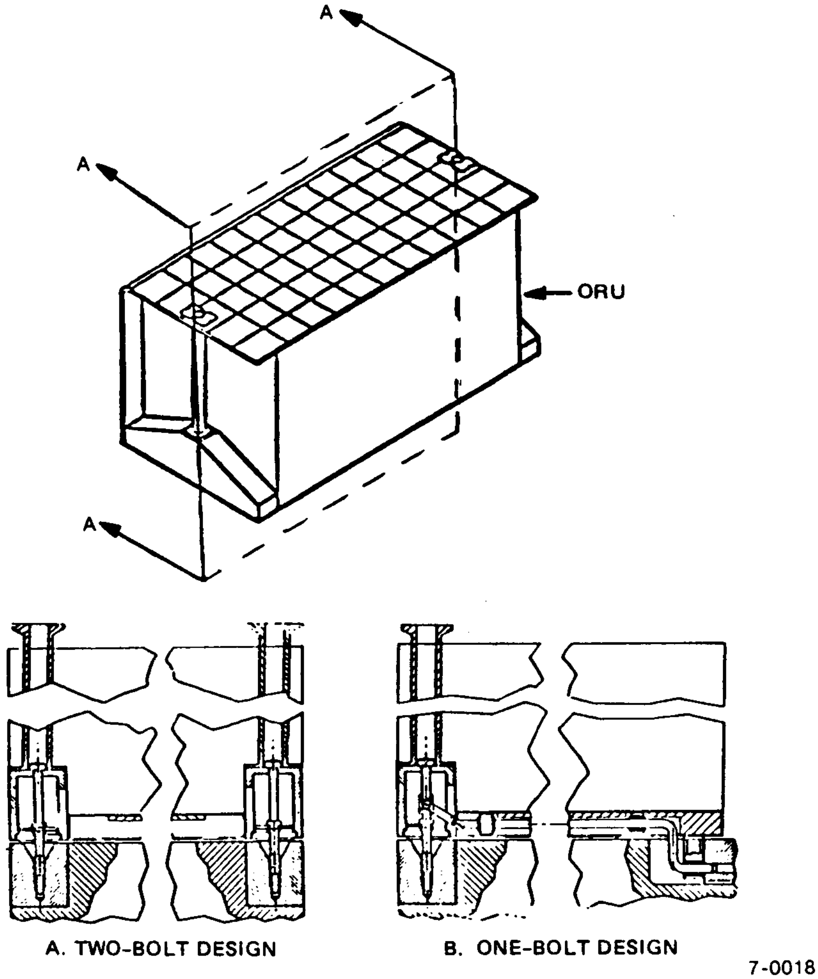

Figure 3. Variations of the Baseline SIC Design

The virtues of the baseline SIC design include flexibility, efficiency, simplicity, cost-effectiveness, ease of operation, and universality of application. The fact that the design permits a vertical (normal) approach to the platform yields flexibility in planning for platform layout; also, payloads

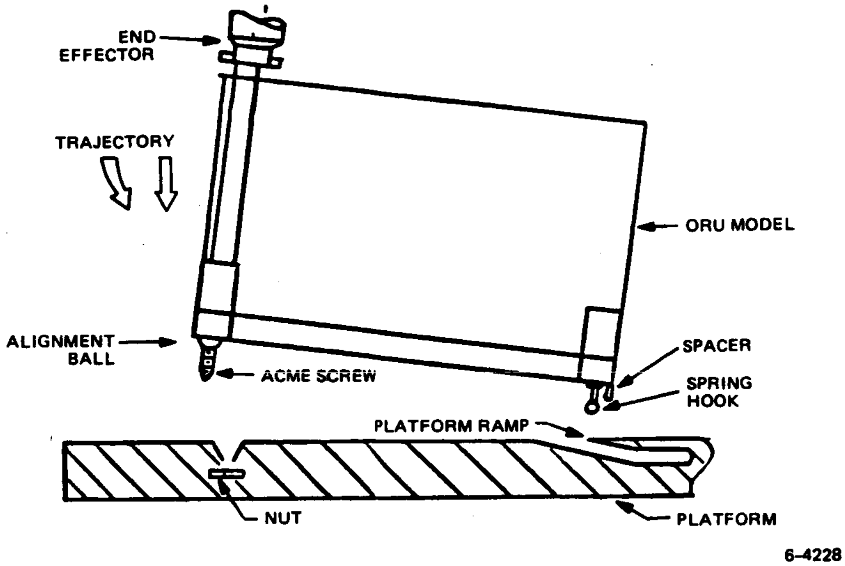

Figure 4. Active/Passive Three-Point Support

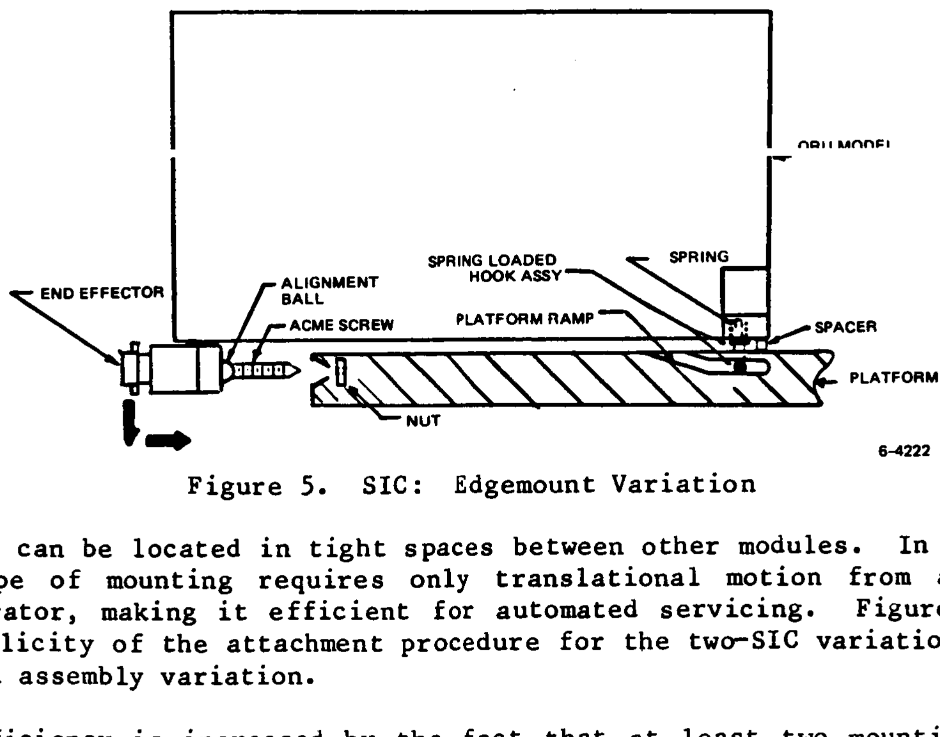

Figure 5. SIC: Edgemount Variation

and ORUs can be located in tight spaces between other modules. In addition, this type of mounting requires only translational motion from a robotic teleoperator, making it efficient for automated servicing. Figure 6 shows the simplicity of the attachment procedure for the two-SIC variation and the push-rod assembly variation.

Efficiency is increased by the fact that at least two mounting points are loaded for each bolt turned. This is especially important for servicing by an astronaut because it has a direct effect on the number of ORUs that can be exchanged, because it is a time-critical operation. A trade study on this subject indicated that, to exchange as many as six ORUs in the six-hour EVA time frame, the design could allow only two bolts per ORU, as plotted in Figure 7.

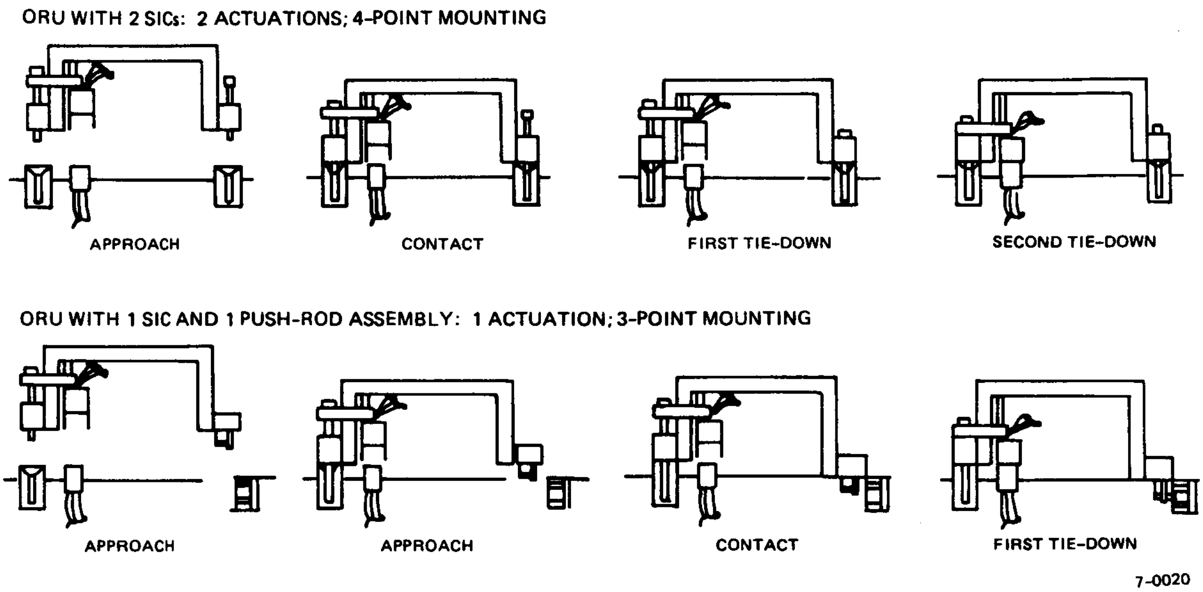

Figure 6. Attachment Procedure for Two Variations of the SIC Baseline

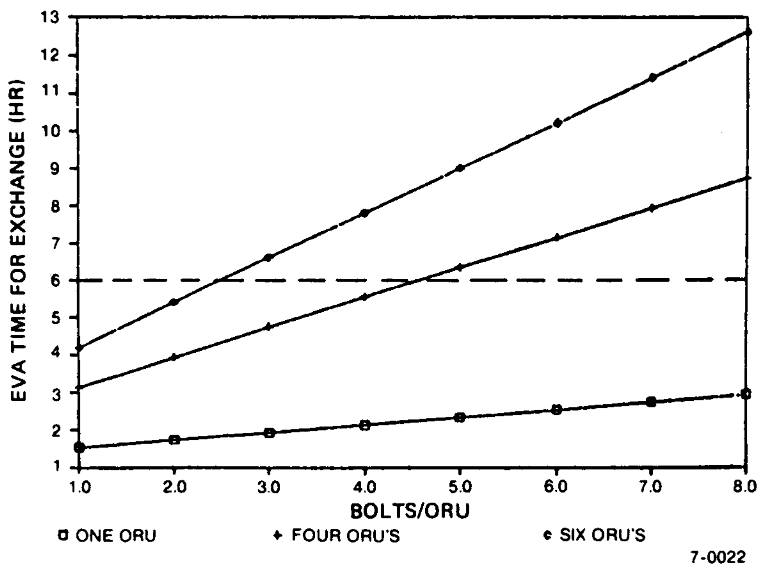

Figure 7. Results of Trade Study on ORU Exchange Times in EVA

A major benefit of the SIC is that it can be fitted with a variety of connectors, including specialized coaxial connectors, multipin electrical connectors and heat conduction pads. Figure 8 shows a load spreader beam fitted with heat pipe disconnects as well as electrical connectors.

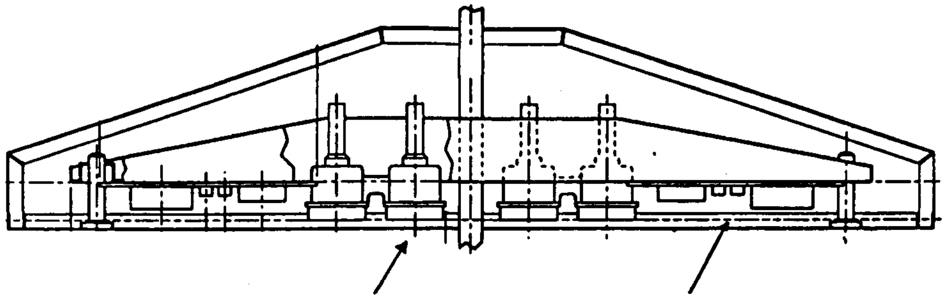

Figure 8. SIC Assembly with Heat Pipe Disconnects

FABRICATION AND TEST

A multifaceted test program was developed for the baseline design, and three types of models were fabricated.

Half-Size Model

In the first stage--design feasibility test--a half-size ORU model demonstrated the basic functionality of the design and its compatibility with available robotics. The robot at RCA's Advanced Technology Laboratory (ATL) was used for this test. The design configuration was that of a three-point mount using a load-spreader beam at one end of the ORU combined with the push-rod and shear-pin assembly. This variation carried the greatest risk of all the concepts, yet also the important potential for single-action attachment, i.e., loading all three restraint points by turning one screw. The model was built of plexiglass to view the working parts, which were made of aluminum. A close-up of the load-spreader beam with the screw and sliding connector plate is shown in Figure 9. The model consisted of the load-spreader beam with push-rod assembly attached to a baseplate and the whole covered with a shroud. A plexiglass stowage mockup contained the mating parts. Because this test emphasized robot handling, greatest attention was given to the design and fabrication of the attachment screw, its mating socket, the restraint pins and sockets, the connector plate, and the gripper plate that interfaces with the robotic end effector. Working connectors were not used. A platform mock-up was also built for this test, complete with mating parts and two mock ORUs to delineate the ORU insertion space.

The test of the half-size ORU/SIC was coordinated with engineers at the robotics facility at ATL. First, a special end effector for their PUMA 762 was adapted from a standard true-parallel jaws gripper to provide for alignment adjustment and the bolt turning action. An alignment cone with adjoining V-blocks, mounted inside the jaws, permitted angular and lateral alignment. An allen wrench protruding from the center of this cone was turned by a motor-driven belt to loosen and fasten the bolt within the ORU/SIC handle. The end effector and the corresponding gripper plate of the handle are shown in Figure 10. In addition, a miniature CCD camera was fixed to the back side of the end effector for targeting.

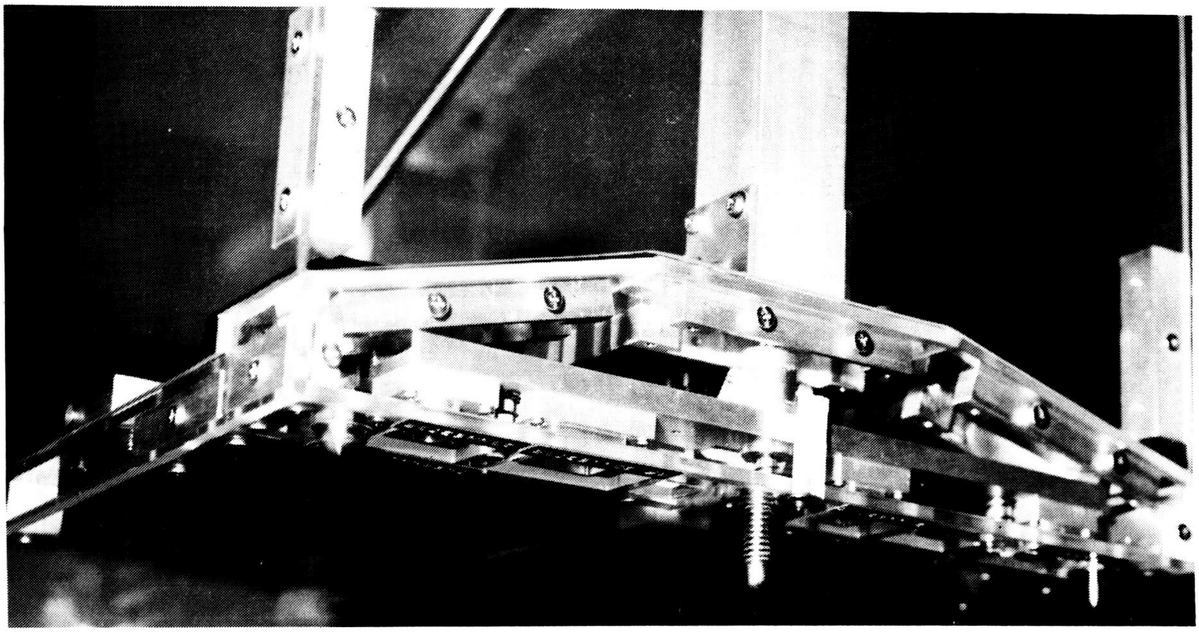

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Figure 9. View of SIC Plexiglass Model Showing Load-Spreader Beam and Sliding Connector Plate

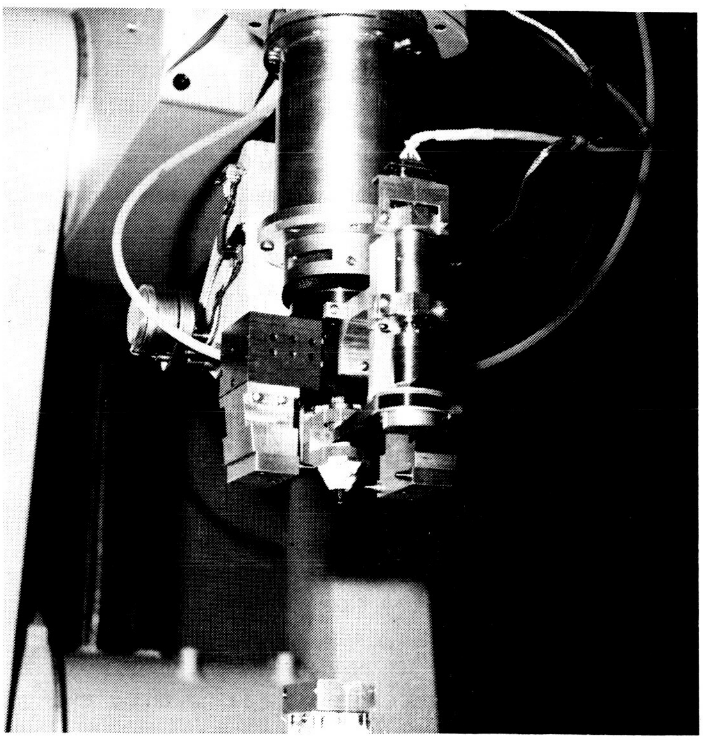

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Figure 10. Parallel Jaws Gripper Adapted for ORU Exchange at ATL

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A six-axis force/torque sensor was situated between the end effector and the robot arm. The alignment mechanisms acted in cooperation with this sensor by means of a compliance control loop. Software written for the test provided the operator the choice of performing the ORU exchange via preprogrammed instructions or manual joy stick control. The operator was located in a separate control room with a view into the robotics lab. Cameras and TV monitors provided remote viewing. An interactive voice control system activated the preprogrammed task segments and the camera position controllers. Using a combination of automated and manual operations, the operator successfully directed the robot to release the model from its stowage location, carry it to the platform mock-up, maneuver it into its mounting position between adjacent ORUs, and firmly attach it to the platform. The entire operation took an average of 4.5 minutes. Figure 11 shows the model about to be inserted onto the platform mock-up by the robot.

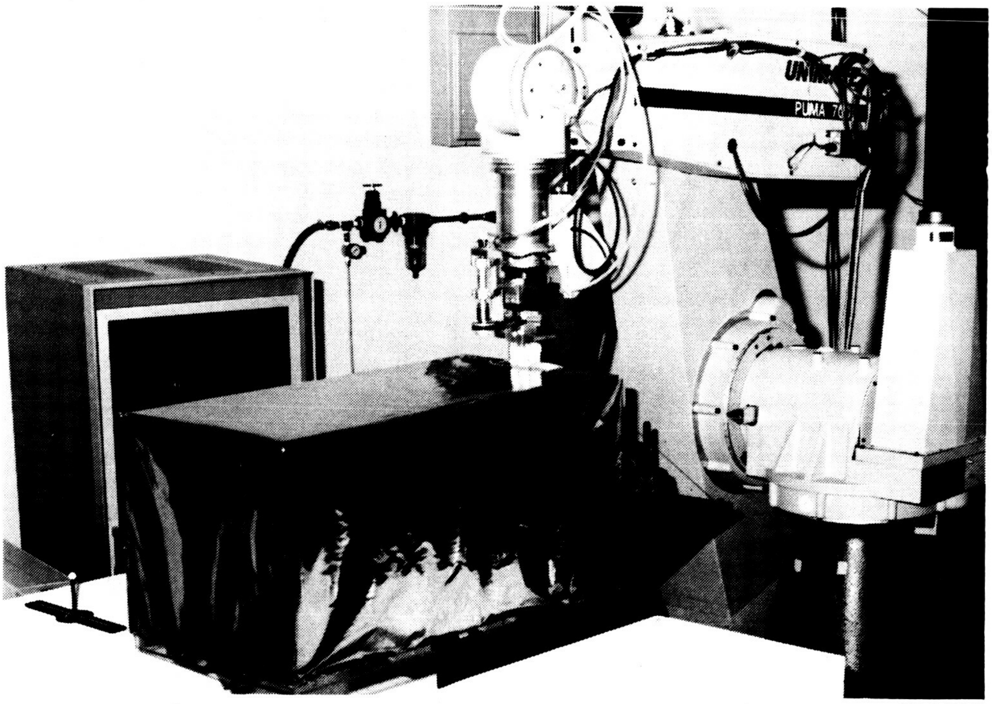

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Figure 11. ORU Insertion onto Platform by PUMA 762 Robot

After successful completion of the test of the three-point mount configuration, the model was reconfigured to represent a payload requiring six mounting points. The push-rod assembly was replaced with four additional bolts around the periphery of the baseplate, and their corresponding sockets in the stowage mock-up. This configuration was designed to be handled by a "dual-arm" robot with appendages that cooperate with each other.

A PUMA 560 was added to the robotics laboratory; the newly introduced robot and the original PUMA 762 communicated and worked cooperatively with each other, just as a dual-arm robot would. They effectively carried out the payload exchange scenario.

Full-Size Mechanical Test Model

To conduct proof-of-concept testing in a more realistic, space-servicing environment, full-scale ORU exchanges were effected in a NASA robotics facility. In a cooperative effort with Goddard Space Flight Center (GSFC) and Marshall Space Flight Center (MSFC), automated exchanges of four ORU/SIC designs were performed using the engineering test unit of the Integrated Orbital Servicing System (IOSS) as shown in Figure 12. This system, located at MSFC in Huntsville, Alabama, depicts the servicing kit of the Orbital Maneuvering Vehicle (OMV) docked to a space platform mock-up with three ORUs. The test ORU model could be used to represent a two-actuator (see Figure 13), one-actuator (similar to that tested at ATL), one-actuator edge-mount, or one-actuator advanced technology SIC configuration. These last two designs were considered purely experimental and were meant to take advantage of advanced robotics. The model was 30 in x 30 in x 30 in and weighed a mere 11.5 lb to be compatible with the IOSS wrist-joint torque limit of 60 ft-lb.

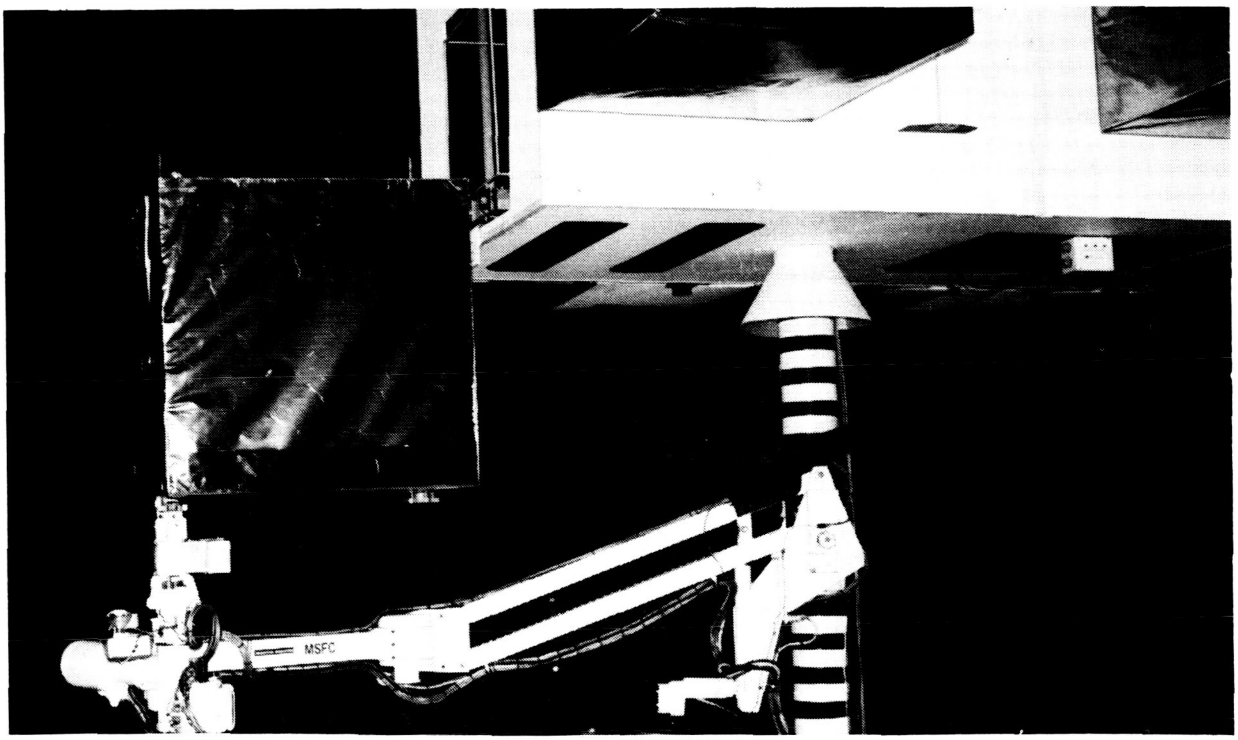

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Figure 12. IOSS Engineering Test Unit with Astro-Designed ORU Model

The test involved exchanging each ORU/SIC variation between the space platform mock-up and the OMV stowage rack using the 13-foot IOSS servicer arm. A mock-up of the NASA Module Servicing Tool (MST) was used as an end effector throughout; however, the edgemount was exchanged using the end effector that was integral to the IOSS arm. This was done to demonstrate other servicing tool designs.

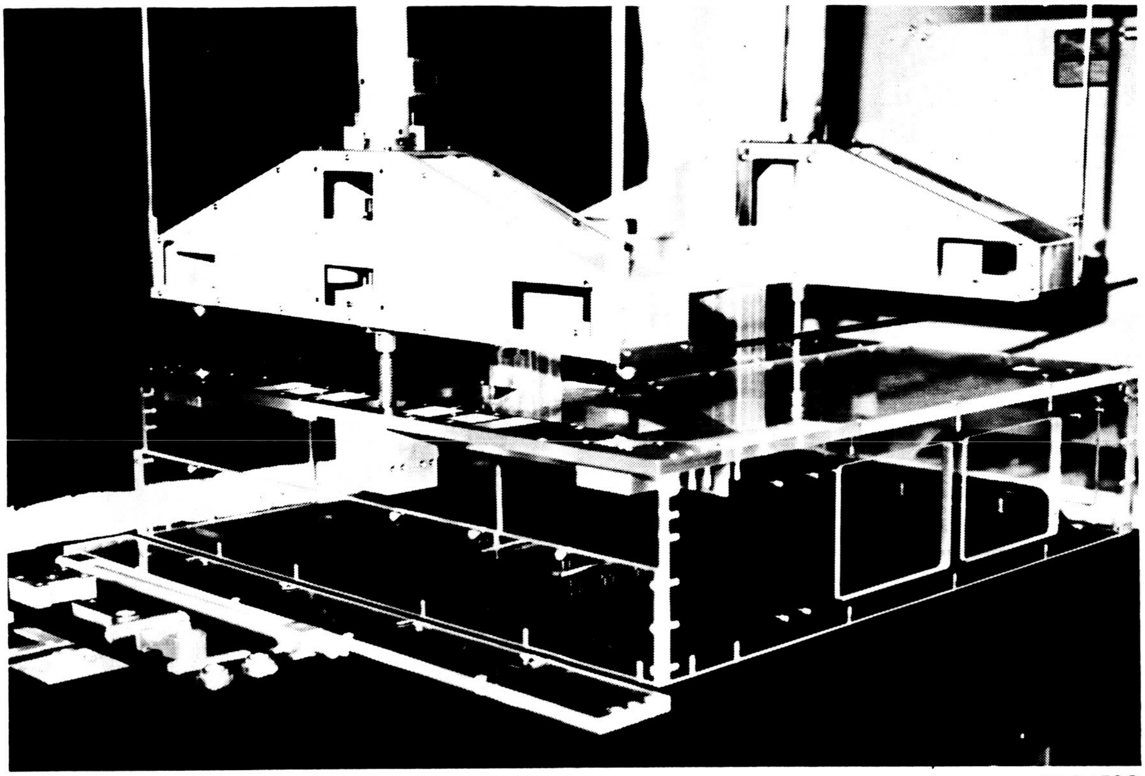

Figure 13. SIC Mechanical Test Model: Two Load-Spreader Beam Variation

These tests demonstrated the functionality of each ORU/SIC design and showed that exchanges of each could be performed using only the passive compliance of the servicer arm. Experience from this test will aid in design refinement and will become a means of extrapolating to future space-servicing scenarios.

Full-Size, Lightweight Model for EVA Simulation

Finally, to ensure that the robotically optimized ORU design is compatible with EVA operations, a full-size, lightweight model was fabricated. This test addressed the issues of visibility and ease of insertion by an astronaut. A foamboard model was fitted with hardware representing the attachment screw and alignment cone, and was equipped with a detachable MST mock-up. The model was also equipped with guides to assure that the screw would be inserted in its socket. An appropriately sized box represented the insertion space expected to be available. Although the model was lightweight, it was suspended from the ceiling with springs to simulate a 0-g environment. The MST mock-up gave the person handling the model a feel for the distance and placement of the model from the handles of the tool an astronaut would use. The knowledge gained from this test will be used to enhance the baseline design for test at a 0-g environment such as one of NASA's neutral buoyancy facilities.

CONCLUSION

In-orbit servicing of spacecraft has been proposed to increase operational lifetime and provide multiple-payload configurations. Viable concepts must be verified, and their impact on spacecraft design determined. Servicing methods must be cost effective, independent of the type of payload or subsystem, and easily performed by astronaut or robot. Work at Astro has made significant progress in defining a realistic approach to spacecraft servicing. The connector design concepts have been established as strong candidates for standard Space Station ORU/payload attachment devices. The design incorporates simplicity of operation and versatility of use.